VARIATION IN INFESTATION AND FACTORS AFFECTING OVIPOSITION OF MANGO PULP WEEVIL, Sternochetus frigidus (Fabr.) (Coleoptera:Curculionidae) ON MANGO Mangifera indica IN NORTHERN PENINSULAR MALAYSIA

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by

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LIST OF ABBREVIATION AND SYMBOLS

^0C	Degree celcius
a.s.l.	Above sea level
cm	Centimeter
DAFI	Day after flower induction
E	East
g	Gram
GC-MS	Gas cromatography-mass spectometry
GPS	Global Positioning System
ha	Hactare
kcal	Kilocalories
kJ	Kilojoules
Km^2	Kilometre square
l	Liter
m^2	Metre square
MARDI	Malaysian Agriculture Research and Development Institute
MARA	Majlis Amanah Rakyat
ml	Milimeter
mm	Milimeter
SE	Standard Error
MPW	Mango pulp weevil
MSW	Mango seed weevil
N	North
SE	Standard error
UiTM	Universiti Teknologi MARA

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VARIASI SERANGAN DAN FAKTOR YANG MEMPENGARUHI OVIPOSISI KUMBANG PENGOREK BUAH MANGGA Sternochetus frigidus (Fabr.) (Coleoptera:Curculionidae) PADA MANGGA Mangifera indica DI UTARA SEMENANJUNG MALAYSIA

ABSTRAK

Potensi ancaman kumbang pengorek buah mangga kepada industri mangga Malaysia telah disiasat dengan memeriksa buah-buahan yang diserang oleh MPW dari pelbagai kebun serta pokok-pokok yang ditanam di kawasan perumahan, dari tempat-tempat terpilih di utara Semenanjung Malaysia. Serangan yang lebih tinggi oleh MPW dicatatkan di Kedah (65%) seterusnya Pulau Pinang (60%) dan Perlis (45%) dan 22% daripada ketiga-tiga negeri mengalami serangan yang teruk. *Sternochetus frigidus* memilih untuk menyerang mangga Gajah (min kumbang setiap buah-buahan=6.4±5.86) lebih daripada Siku Raja (3.6±0.93), Chok Anan (3.0±0.98), Sala (2.8±0.60) dan Siam (2.7±0.47). Ciri-ciri buah seperti berat, ukur lilit, panjang, lebar dan ketebalan isi buah mempengaruhi serangan MPW (semua $p<0.05$) ke atas Chok Anan dan India. Faktor-faktor lain seperti umur pokok, penggunaan tanah di kawasan sekitar dan ketinggian kawasan tanaman tidak mempengaruhi serangan kumbang. Oviposisi MPW di peringkat fenologi buah yang berbeza (Chok Anan dan Sala) telah dikaji di ladang mangga. Kumbang betina telah memilih untuk mula bertelur di bahagian tengah kulit mangga yang bersaiz kecil (4 - 6 cm) terutamanya pada kultivar Chok Anan berbanding dengan Sala (semua $p<0.05$). Hal ini kerana kultivar Chok Anan mempunyai lebih kompoun-kompoun penarik untuk MPW beroviposisi. Pemilihan tempat untuk oviposisi memberikan peluang yang tinggi untuk larva membesar. Faktor-faktor persekitaran yang sesuai seperti suhu, hujan, kelajuan angin, dan kelembapan udara juga mempengaruhi aktiviti oviposisi MPW. Keputusan dari kajian ini telah mencadangkan tempoh masa terbaik untuk mencegah perosak ini dari menyerang buah mangga iaitu sebelum saiz buah Chok Anan mencapai 4 cm dan Sala 6 cm (3 - 4 minggu selepas mangga berbuah). Kajian ini juga mendapati komposisi sebatian meruap pada kedua-dua kultivar buah mangga, Chok Anan dan Sala sebagai penarik oviposisi kepada kumbang betina. Hasil analisa Gass chromatography-massa spectometry (GC-MS) buah Chok Anan dan Sala (isi dan kulit) mendapati 18 dan 19 kompaun didapati pada isi dan kulit buah Chok Anan, manakala 12 dan 25 kompoun didapati dalam isi dan kulit buah Sala. Terpinolene, limonene, pinene <alpha->, myrcene, phellandrene <alpha->, cymene <para->, linalool dan caryophyllene <(E) -> telah dikenal pasti sebagai penarik oviposisi. Kandungan terpinolene lebih tinggi pada Chok Anan (27.201% - isi dan 25.041% - kulit) berbanding dengan kultivar Sala (0.055% - kulit). Oleh itu, sebatian lapan kompoun yang ditemui ini merupakan penyumbang utama kepada aroma untuk menarik MPW beroviposisi pada kedua-dua kultivar dan keputusan mendapati Chok Anan mempunyai lebih tarikan untuk MPW beroviposisi (5.0±0.82) berbanding Sala (0.15±0.04).

VARIATION IN INFESTATION AND FACTORS AFFECTING OVIPOSITION OF MANGO PULP WEEVIL, Sternochetus frigidus (Fabr.) (Coleoptera:Curculionidae) ON MANGO Mangifera indica IN NORTHERN PENINSULAR MALAYSIA

ABSTRACT

Potential threat of Mango Pulp Weevil (MPW) to Malaysian mango industry was investigated by examining infested fruits from various orchards and scattered trees in residential areas in selected places in the northern peninsular Malaysia. Higher infestation of MPW was recorded in Kedah (65%) followed by Penang (60%) and Perlis (45%) and 22% from these states suffered severe infestation. *Sternochetus frigidus* preferred mango cultivars Gajah (mean weevil per fruit = 6.4±5.86) better than Siku Raja (3.6±0.93), Chok Anan (3.0±0.98), Sala (2.8±0.60) and Siam (2.7±0.47). Fruit parameters such as weight, perimeter, length, width and thickness of flesh influenced MPW infestations (all $p<0.05$) on fruits of Chok Anan and India. Other factors such as age of trees, land use in the surrounding area and landcape elevation had no influence on weevil infestation. Oviposition of MPW in different phenological stages of mango fruits (Chok Anan and Sala) was studied in mango field. The majority of female MPW oviposit on the medium part of small size mango fruits (4 – 6 cm) and had highly preference towards Chok Anan compare to Sala cultivar (all $p<0.05$). The selectivity of ovipositing females give a high chances for larval development completion. Suitable environmental factors; temperature, rainfall, wind speed and relative humidity also affected oviposition activity of MPW. The result from this study suggest the best timing period to prevent this pest from infesting mango fruits best before Chok Anan fruit sizze reach 4 cm while Sala 6 cm

(3 - 4 weeks after fruiting). This study also discovered the compositions of volatile compounds in both Chok Anan and Sala mango cultivars as oviposition attractants to female of MPW. Result from Gass chromatography-mass spectometry (GC-MS) for Chok Anan and Sala mango cultivar fruits (pulp and peel) showed that 18 and 19 compounds were found in Chok Anan mango pulp and peel while 12 and 25 compounds were found in Sala pulp and peel. Terpinolene, limonene, pinene <alpha->, myrcene, phellandrene <alpha->, cymene <para->, linalool and caryophyllene <(E)-> were identified as oviposition attractant. Terpinolene was highly found in Chok Anan (27.201%– pulp and 25.041 % – peel) cultivar compare to Sala (0.055% - peel). Thus, these eigth compounds were the key contributors to the aroma of MPW oviposition attractant in both cultivars and it found that MPW highly prefer ovipositing on Chok Anan (5.0±0.82) compare to Sala (0.15±0.04).

CHAPTER 1

INTRODUCTION

1.1 Background

Mango is one of the most consumed fruits, popularly grown in northern peninsular Malaysia because of suitable climate (25.1^{0}C to 32.1^{0}C, 70 to 98% relative humidity, 2334 mm average rainfall) and favourable condition for its growth. Mango becomes the major side income for farmers in northern area especially in Kedah and Perlis. However, the quantity and quality of mango production depends on many factors such as mango variety, quality of seeds, agronomic practices as well as pest and disease control. In Malaysia, several mango cultivars are planted for example Harumanis (MA128), Sala (MA164), Chok Anan (MA 224), Telur, Epal, Siam, Gajah and Siku Raja.

Mango is one of the important exported fruits in Malaysia after water-melon, banana, papaya, durian, pineapple, startfruit, jackfruit and mangoesteen (Appendix 1) (Department of Agriculture Malaysia, 2011). Both fresh mango and mango products were exported to Japan, Singapore, Brunei, Hong Kong, Mexico, Brazil dan Pakistan (DOA Sarawak, 2013). Department of Agriculture Perlis (2013) reported in 2010 that 3.1 metric tonne of Harumanis were exported to Japan at a market value of RM100.00 per kilogram. The quantity of export is expected to increase to 100 metric tonne in 2020. Other potential importing countries include Singapore and Hong Kong (UTUSAN, 26 April 2013). In 2011, Malaysia were reported to export 1705.0 matric tonne of mango fruits which value RM3,421,000.00 that contributed to Malaysia economic growth.

According to Tengku *et al.,* (1996) Chok Anan is a new cultivar that is introduced from Thailand which has high potential for commercialization. This mango tree can produced fruits as fast as 6 months after planting and for two years old Chok Anan mango tree can produce between 60 to 80 fruits in a season. Chok Anan mango tree is a non-seasonal mango which can produce high quantity of fruits even during rainy season. Sala can produce more than 100 fruits per tree per season. This cultivar bear fruit earlier in every season compare to Chok Anan, Harumanis and other cultivar.

Cheah *et al*., (2009) reported that, the mango fruit is fully ripe between 13 to 16 weeks after fruit set (AFS). There are three stages of fruit growth; at week 1 to week 2 AFS, the elongation of fruit is very slow. Second stage (week 3 to week 9 AFS) is the growing stages where mango fruit elongates very fast and the last stage is after week 9 AFS where the fruit growing becomes slow again.

Tengku *et al*., (1996) reported that Chok Anan (MA 224) which is a new cultivar originated from Thailand have more sweet aromatic flavour compared to another local variety, Sala and the odour increases as the fruit is ripening. The flesh of ripe fruits has the total soluble solid of 14 - 16 %. Sala flesh is yellowish and not very sweet (total soluble solids 10 - 12%). Mango generally high in vitamin C and potassium besides natural occuring sugar which is good for human health (USDA, 2012).

Perlis is the most popular mango producing state in Malaysia because of her mango product. Harumanis (MA128) is commercialized as the highest quality mango and highly demanded not only in Malaysia but also in Japan. Mango varieties commonly planted in Perlis are Harumanis, Sala, Chok Anan, India, Siam, Telur, Pauh, Mangga and Siku Raja.

In Kedah, mangoes are mostly grown around houses or residential areas for own consumption. Varieties such as Sala, Chok Anan, India, Siam, Epal, Siku Raja, Gajah, Bemban, Sekaya, and Tong Dam are widely planted in this state.

Similar to Kedah mango trees in Penang are grown for home consumption and planted in the residential area. Siam, India, Sala, Epal, Telur, Mangga, Gajah, Cultivar A and Cultivar B are popularly planted in Penang. Mango trees selected for this study are mostly backyard trees which was not properly managed by the owner and served as reservoirs of pests especially MPW.

Presently, mango pulp weevil (MPW), *Sternochetus frigidus* (Fabr.) (Coleoptera: Curculionidae) becomes the most serious pest in mango plantations after fruit flies (Tephritidae: Diptera), thrips (Thysanoptera), and mango stem borer (Cerambycidae: Coleoptera) (Ithnain *et al*., 2006). In Malaysia, two species of mango weevils are identified, *S. frigidus* (Ithnain *et al*., 2006) and *S. mangiferae* (Fauziah and Kamarulnizam, 2008). Based on the Department of Agriculture Sarawak (2013), *S. mangiferae* or known as mango seed weevil was declared as a quarantine pest in Malaysia under Plant Quarantine Act 1 976.

De Jesus *et al.,* (2002) reported that MPW occurs in Malaysia, Thailand, North-east India (Assam and Tripura), Bangladesh, Burma, Singapore and Indonesia. This insect is an important quarantine pest of mango in the Philippines and found only in the western island of Palawan. Infestation of MPW occurs inside the fruit. Based on De Jesus (2008) infestation of MPW starts in young fruits from 3.5 cm in size until fruit maturity but the infestation is undetectable until the adult weevil bores out from the mango flesh and leaves the frass within the fruit.

Mango seed weevil (MSW), *S. mangiferae* (Fabr.) has a wider spread than the MPW. It was reported in Asia (Malaysia, the Philippines, India, Sri Lanka, Bangladesh, Indonesia, Thailand, Vietnam, Myanmar, Nepal, Oman, Pakistan, United Arab Emirates, Hong Kong and Bhutan), Africa, North America, South America and Oceania (Grove and De Beer, 2007; Catinding and Heong, 2011). This weevil attacks small mango fruits of "lime size" (2 – 4 cm) in diameter by making a shallow, boat shaped depression and lays single egg in each place (Verghese *et al.,* 2005b).

Some volatile compounds in mango fruits are found to attract the weevils to lay eggs on the fruits. According to De Jesus *et al.,* (2004), six blended components of floral volatiles from the cultivar "Carabao"; acetic acid (0.7%), decane (0.3%), acetone (4.4%), linalool (82.2%), ethyl benzoate (11.4%) and 2-methyl heptenone (1.0%) contribute of 70% attraction to MPW. However, among these compounds, only acetic acid (Tamura *et al.,* 2000), linalool (Tamura *et al.,* 1999) and ethyl benzoate (Pino *et al.,* 2004) are suspected to strongly attract the weevils.

In addition, the behaviour of *S. frigidus* is also important in strategizing control management. According to De Jesus *et al.,* (2003), this weevil usually crawls around instead of flying from tree to tree. It is active at night from 2200 h - 0200 h and rest during the day. Usually, MPW hides in tree bark and feeds on mango flowers during the flowering season. The mating and oviposition process usually take place during day time.

A lot of studies on MPW are carried out in the Philippines where weevil infestation is serious. Life history of the weevil, its host range, feeding and reproductive behavior at different fruit phenology, oviposition preferences, field infestation and chemical control have been investigated. In addition, sex discrimination of the weevils and floral volatile that are attractive to MPW have been explored by many researches (De Jesus and Cortez, 1998; De Jesus and Gabo, 2000; De Jesus *et al.,* 2002; De Jesus *et al.,* 2003; De Jesus *et al.,* 2004 and De Jesus, 2008).

Compare to MPW (*S. frigidus*)*,* MSW (*S. mangiferae*) is better studied in most of the mango growing countries like Hawaii (Hansen *et al.,* 1989; Woodruff, 1970; Follett, 2001; Follett and Gabbard, 2000), India (Verghese *et al.,* 2005a), Africa (Grove and De Beer, 2007), South Africa (Louw, 2008), Tanzania (Mulungu *et al.,* 2008) and Kenya (Muriuki *et al.,* 2011).

In view of limited information and research on *S. frigidus* in Malaysia, this study was undertaken to provide base line information and estimate on its potential threat to mango industry. The timing of its infestation on preferred size of mango fruits and factors that contribute to its infestation would be useful in formulating a control strategy against this pest.

1.2 OBJECTIVES

This research was conducted to achieve the following objectives:

1. To examine the distribution pattern of *S. frigidus* among mango cultivars (*Mangifera indica*) in Northern Peninsular Malaysia.

2. To identify the oviposition preference of *S. frigidus* on specific stage (size) of Chok Anan and Sala fruits.

3. To identify the chemical attractant (volatile compounds) responsible for infestation of *S. frigidus* on fruits of Chok Anan and Sala.

CHAPTER 2

LITERATURE REVIEW

2.1 Mango (*Mangifera indica* L.) as a host plant

Mango or *Mangifera indica* is a part of Anacardiaceae family which consists of 69 species of *Mangifera* genus and over 500 identified varieties (Delgado *et al.,* 2011 and Mirghani *et al*., 2009). The genus *Mangifera* originates in Tropical Asia but *M. indica* (mango) originates from India and Myanmar (Kostermans and Bompard, 1993) and is well distributed in tropical and subtropical regions (Bally, 2006 and Delgado *et al.,* 2011). Bally (2006) reported that the other common names of mango are “mangga” or “mempelam” (Malaysia and Indonesia), “aam”, “am”, “amb” (Hindi), “ampleam” (Tamil), “mamung” (Thailand), and also “paho” (the Philippines).

In Malaysia, two mango fruiting seasons are identified. The main season starts in March until May and August until October is the off season. Mango grows well in Malaysia because of the equatorial climate; temperature range between 24°C to 27°C with seasonal rains (Dag *et al*., 2000). According to Kwee and Chong (1994) mango has a minimum temperature limit of 1 – 2°C and maximum limit of 43°C for good growth and Malaysian temperature lies within the limit.

A mango tree is large, deep-rooted and long-lived evergreen tree which can grow up to 15 - 30 meters but for most cultivated tree, it can grow to 3 - 10 meters tall when fully matured (Bally, 2006). It has simple, alternate, and oblong leaves 15 - 30 cm long that are yellow-green, purple, or copper colour when young and turn to deep green when the tree matures. Mango suitable to be plant in different type of soil textures including sands, sandy loams, loams, sandy clays loams, clays, clay loams, and sandy clay (Bally, 2006).

Mango fruits are high in vitamin C (43 %) besides other vitamin such vitamin A and B also other nutrients (Hussain *et al*., 2002 and Ara *et al*., 2005). 100 grams of ripe mango provide 250 kJ (60 kcal) energy for adults consumption. Generally, fresh mango fruit composition contains moisture (79.20 – 82.00 %), total soluble solids (12.90 - 20.80 %), total sugars (10.00 - 17.30 %), non-reducing sugars (7.27 - 12.35 %), ash content (0.49 - 0.58 %) and crude protein (0.38 - 0.62 %) (USDA Nutrient Database, 2012) (Appendix 2).

Ueda *et al*., (2000) reported the major content of dried mango was found to be carbohydrate, while 60 % of the compound are sugars and acids which are the major compounds contributing to fruit sweetness and acidity (Malundo *et al*., 2001). Mango fruit flesh taste is highly dependent on the balance between organic acids and total soluble solid (Medlicott and Thompson, 1985), in which high in total soluble solid resulted in the sweetness taste also aroma of mango fruits. On the other hand, organic acid such as citric acid was found dominant in mango fruit than malic acid, however the contect of citric acid decreased gradually in the maturity stage while malic acid was nearly constant (Ueda *et al*., 2000).

A panicle of mango flowers contain 300 - 6000 hermaphrodite and male flowers while number and flower types depends upon the cultivars (Delgado *et al.,* 2011). The flowers are small and monoecious because both male and hermaphrodite flowers are found within single inflorescence. Pollination occurs by the aid of insects such as flies, wasps, and bees. A dry season during the flowering period promoted to high quality fruit production (Mossler and Nesheim, 2002).

Mango fruits are classed in a drupe group because it is fleshy with a single seed enclosed in a lathery endocarp (Bally, 2006). The fruit shape varies according to variety or cultivar and may be round or oval. The colour of immature fruit is green, gradually turning to yellow, orange, purple, red, or combinations of these colours as the fruit matures. Mature fruit has a characteristic fragrance and a smooth, thin, tough skin. The flesh of ripe mangos is pale yellow to orange and is juicy, sweet, and sometimes fibrous. The single seed usually is large and flattened and adheres to the flesh. The seed contains monoembryonic and polyembryonic embryo depending on variety or type.

Mangoes are commonly peeled and eaten fresh as a dessert fruit but are also used in juice preparation and made into preserves, jam, dried slices, and pickles. The insect pest problems in mango remain the same in the traditional mango producing areas.

A report by the Department of Agriculture Malaysia (2013) shows that mango is widely grown in Malaysia and in 2011, the mango plantation area occupies 4638.4 hectare (ha) of agricultural land in Peninsular Malaysia. In Perlis 532.9 ha are planted with mango, Kedah, 331.2 ha and Penang 120.5 ha. Total area of mango plantation is 4638.4 ha including in Sabah and Sarawak. In addition, mango production is increasing from year 2001 to 2002 and maintains until 2011 with a small fluctuation. In 2000, Malaysia produced 14966.6 tonnes of mango products including fresh and processed mango while in 2011, the production rose to 2102.5 tonnes (Appendix 3).

2.2 Pest of Mango (*Mangifera indica*)

About 260 species of insects and mites are reported as minor and major pests of mango. Among them, 87 species are fruit feeders, 127 are foliage feeders, 36 are inflorescence feeders, 33 occupy buds, and 25 feed on branches and trunks (Pena *et al.*, 1998). Common pests of mango in Malaysia are fruit fly (*Bactrocera carambolae* Drew & Hancook and *Bactrocera papayae* Drew & Hancock), thrips (*Thrips hawaiiensis* Morgan, *Scirtothrips dorsalis* Hood, *Frankliniella schultzei* Trybom, *Megalurothrips usitatus* Bagnall, *Thrips palmi* Karny, *Haplothrips sp.* Amyot and Serville, *Haplothrips pictipes* Bgn. and *Selenothrips rubrocinctus* Giard), mango leaf cutting weevil (*Deporous marginatus*), gold dust weevil (*Hypomeces squamosus*), mango leaf hoppers (*Idioscopus nitidulus* and *Idioscopus clypealis*), mango shoot borrer (*Clumetia transversa*), mango trunk borer (*Rhytidodera simulans*) and Bombotelia caterpillar (*Bombotelia jacosatrix*) (Tengku Ab Malek *et al.*, 1996; Ithnain *et al.*, 2008; Cheah *et al*., 2009 and Aliakbarpour and Che Salmah, 2012).

Mango tree is very sensitive to pest attack and diseases in the early planting until fruit production (Tengku Ab Malek *et al.,* 1996). The cost of pests and diseases control can achieve up to 40% of production cost. Intensive care is needed in mango planting industry producing high quality fruits for export.

2.3 Mango Weevil

The mango pulp weevil (MPW), *Sternochetus frigidus* (Fabricius) is one of the major pests that currently infesting mangoes in South East Asia such as in Malaysia, the Philippine, Thailand, Singapore, Indonesia and in other Asian countries like Northern India, Bangladesh, Myanmar, Pakistan, and Papua New Guinea (CABI, 2011 and Catinding and Heong, 2011). The seriousness of weevil infestation has been recognized in many mango producing countries when the weevil is declared as a quarantine pest since 1987 by the Plant Industry of the Philippines (De Jesus and Cortez, 1998). In Australia, MSW is also a quarantine pest which threatens the mango industry there (DAFF Australia, 2007). In India, the distribution of MPW has been monitored and is restricted to areas such as Assam, Manipur, Meghalaya, Tripura and West Bengal (MAI, 2005 and Pinese and Holmes, 2005).

Department of Agriculture Sarawak declares that, MSW is a quarantine pest. A close relative of *S. frigidus*, *S. mangifera* (Fabr.) was reported by Fauziah and Kamarulnizam (2008) to attack mango plantation in Chuping, Perlis in 2006. However, it has been declared as a quarantine pest in Sarawak (Department of Agriculture Sarawak official website, 2013). Mango seed weevil (also known as mango stone or mango nut weevil, *S. mangiferae*), is damaging mango fruits in several countries (Verghese *et al*., 2005a). It is a key pest in the cultivation of mango world-wide (Grove and De Beer, 2007 and Pena *et al.*, 1998) and has been elevated to the status of a quarantine pest.

MPW is a univoltine insect having one generation per year and sometimes up to two years when enough shelter and food are available. It is a holometabolous insect that consists of four life stages; egg, larva, pupa and adult. The larva of the MPW feeds and develops in mango pulp and the newly developed adult remains in a pupal cell inside the mango fruit until the cell rots (De Jesus *et al*., 2002).

The other species of *Sternochetus*, *Sternochetus gravis* (mango stone weevil), is reported from India by Bhubaneshwari Devi, (2011) but earlier on Schotman (1989) suspected it to be the synonym with *S. frigidus*. Larva of *S. frigidus* was described by Gardner (1934) and Rahman and Ahmad (1972) but detailed description of the species has not been published (Poole *et al.,* 2012). Morphological differences between the MPW and MSW are listed by Poole *et al.,* (2012), CABI and EPPO (2011) and Grove and De Beer, (2007). Both species however, have more or less similar duration of life cycle (De Jesus and Gabo, 2000; Ballock and Kozuma, 1964) and damage the fruit in a similar manner.

Mango weevil have very limited host plants and only mango and wild *Mangifera* (Grove and De Beer, 2007) allow all their life stages to fully develop within the fruits (Ballock and Kozuma, 1964; Shukla and Tandon, 1985). The adults feed on the leaves and tender shoots of mango trees, fly readily, mate and oviposit at dusk (Shukla and Tandon, 1985; CABI and EPPO, 2010). In Malaysia, infestation of *S. frigidus* are also observed on *M. foetida* (bachang) and *M. odorata* (kuinin) (Ithnain *et al*., 2008).

2.4 Morphological characteristics of MPW and MSW

Mango weevils are identified based on their morphological characteristics such as elytra, strial punctures, shape of whitish macula, pronotum, aedeagus, and also adult size. Their behavior also illustrates the species. Both mango weevils (MPW and MSW) look similar to each other but the MPW infests mango flesh or pulp and the MSW eats the seeds (DAFF, 2007). Morphologically, MPW is a small stout hardened weevil (De Jesus and Gabo, 2000). Based on description by De Jesus *et al*., (2002) the antennae, sternum and tarsi in both male and female are morphologically identical. However, sexual difference can be seen at the tergite. Females have seven visible tergites and the last tergite is more strongly sclerotized. However, males have 8 tergites and the 7^{th} and 8^{th} tergites are separated from each other. Tergite 8^{th} is smaller than tergite 7^{th}. EPPO (2011) reported that there are several differences between *S. frigidus* and *S. mangiferae.* The size of *S. frigidus* is 3.8 to 5.9 mm smaller than *S. mangiferae* 7.5 mm to 10.0 mm.

The elytra of *S. frigidus* is narrowing starting from its base to the apex while the odd interstriae except sutural one distinctly costate-tuberculate. The adults have round strial punctures. Whitish macula is fragmented but usually forming a vague anterior inverted triangle inscribing a similar. This insect have smaller black median triangle and a broken posterior band on declivity while the pronotum has erect black scales arranged in medial pair of loose clusters. Male of *S. frigidus* has aedeagus with pair of internal sclerites overlapping apically.

In *S. mangiferae*, the sides of elytra are nearly parallel starting from its base to beyond middle. The strial punctures are rectangular to square in shape. Whitish macula forms a more or less distinct V and transverse posterior band; pronotum with erect black scales scattered over basal part of its pronotal disk. The aedeagus has a pair of internal separate sclerites, not touching apically.

2.5 Biology of mango pulp weevil (MPW)

As a holometabolous insect, MPW has four stages of life cycle; egg, larva, pupa, and adult (Plate 2.1). A complete life cycle takes approximately 182 - 190 days (Ithnain *et al*., 2008). This weevil lays eggs on young fruits and all its subsequent stages are completed within a mango fruit (Lorenzana and Obra *et al.,* 2013). The larvae, pupae and sometimes adult weevils can be found simultaneously in a damage fruit. The weevil completes its life cycle in mango pulp (Lorenzana and Obra, 2013) while its sibling *S. mangiferae* (mango seed weevil – MSW) moves further into mango seed to grow to adults which later escapes from fully ripe fruit through a hole in the skin up to two months after the fruit drop (Ballock and Kozuma, 1964; Cunningham, 1989 and Poole *et al.,* 2012).

2.5.1 Egg of MPW

The shape of MPW egg is oblong about 0.5 mm long and 0.4 mm wide. When first oviposited, the eggs are opaque and later turn to light yellow when developing cranium becomes visible. Adults prefer lay their eggs singly in small mango fruits starting from 3.5 cm in mango size. Female cover the eggs with a sticky black exudate to protect the eggs during incubation period (De Jesus and Gabo, 2000). The weevil eggs hatch about 7 days to larvae that can penetrate into mango fruit flesh to continue living (Catinding and Heong, 2011 and Ithnain *et al*., 2008).

2.5.2 Larva of MPW

De Jesus and Gabo (2000) reported that larva of MPW has five instars where the second, third, fourth, and fifth instars are similar in appearance compared to the first instar except of smaller size. The size of first instar larva is about 2.0 mm long and 0.2 mm wide, while second instar is 2.5 mm by 0.3 mm; third instar 2.8 mm by 0.4 mm; fourth instar 3.7 mm by 0.6 mm and fifth instar 7.0 mm by 2.5 mm.

Each instar has different stadium; for first instar is 6.4 days and second to fifth instar is 13.9 days but Ithnain *et al*., (2008) reported that the larva continues to grow for 30 - 36 days. The larva is typical of the weevil (Scarabaeiform) pearly white in colour and plump, legless, and has well defined head, and prognathous mouthparts. The body colour changes to light brown in the fourth larval instar. It tunnels into the mango flesh and leaves the frass or brown granular feaces behind (De Jesus and Gabo, 2000).

2.5.3 Pupa of MPW

The pupa of MPW is cream to light yellow in colour with a brown head. The average measurement is 8 mm x 4 mm. It lives in a chamber for 5 - 7 days before it developes into an adult (Ithnain *et al*., 2008).

2.5.4 Adult of MPW

Adults can live up to 140 days and stay in the fruit for a few days before they burrow out of the fruits to fly freely. This weevil is active at night (nocturnal) and hides in tree stump or stacking branches during the day (De Jesus *et al*., 2003 and Ithnain *et al*., 2008). Adult of MPW feeds on mango flowers floral secretions, nectars, flower parts and leaves of mango trees (De Jesus *et al.,* 2003 and Ithnain *et al*., 2008).

Oviposition activity begin when mango fruit reach size of chicken egg; ≈ 5 cm (Catinding and Heong, 2011 and De Jesus *et al*., 2003). After mating, gravid female markedly crawl on mango fruit surface in search of an oviposition site. Female start by scratching lightly the fruit surface to prepare for egg deposition. After lying an egg, female cover it with saliva and makes another scratch on the fruit surface near the egg so that latex would cover it and formed as an egg plug (De Jesus *et al*., 2003).

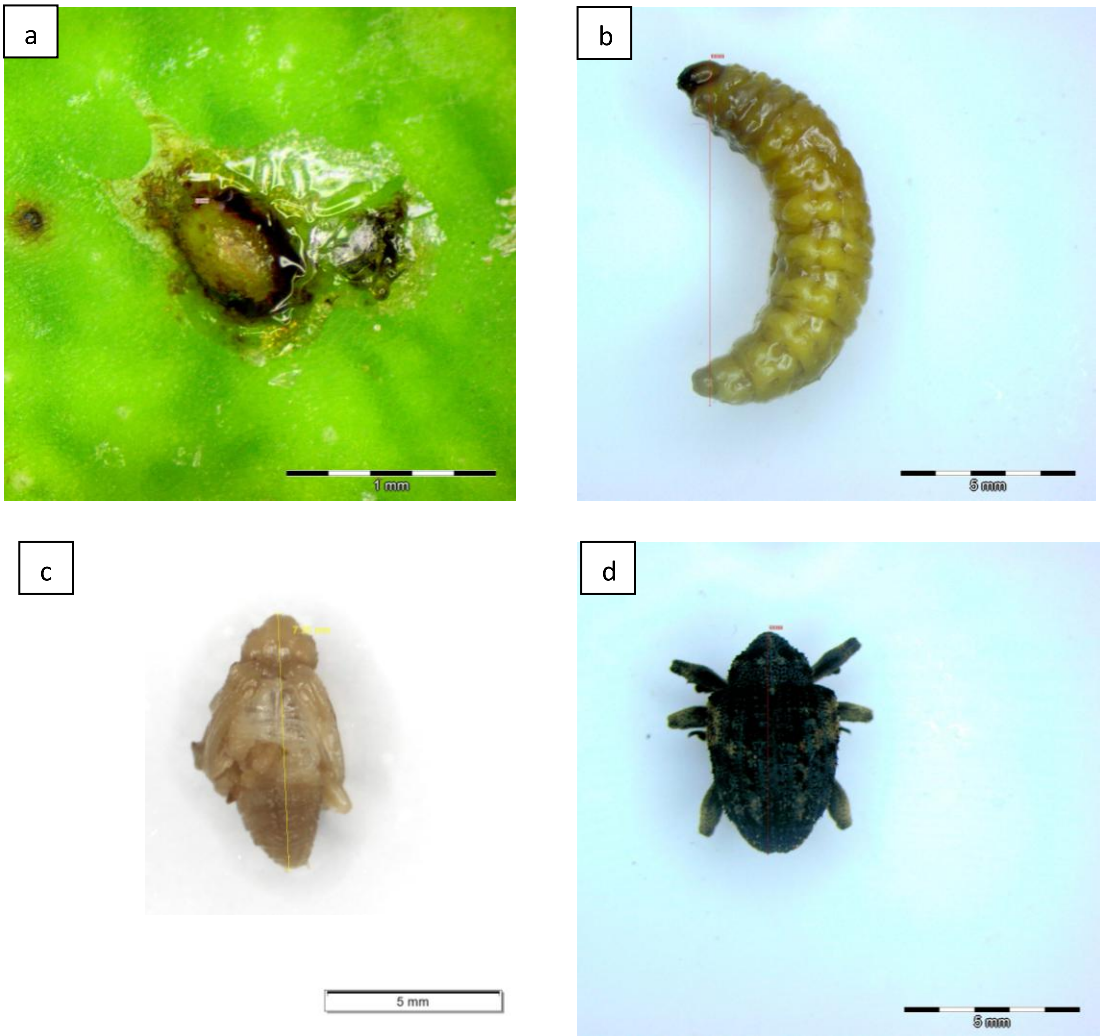

Plate 2.1: MPW life cycle; (a) egg (b) larva (c) pupa and (d) adult.

2.6 The economic importance of MPW in Malaysia

The damage done by MPW is not visible by naked eyes. As the fruits grow, empty eggs on the skin will disappeared and leave the damage undetectable (Tengku *et al.*, 1996). Mango fruits are usually harvested before they are fully ripe and for this matter fruit producers usually failed to detect MPW infestation. The infestation is only visible when a fruit skin is peeled off. The MPW infestations affect fruits by lowering the marketability of mango.

Mango tree is more sensitive towards pests and diseases at early planting until fruit production. The cost of pest and disease control can achieve 40% of production cost. Intensive care of the trees would reduce production cost and ensure high quality fruits especially for export (Tengku *et al.*, 1996).

2.7 Damage by MPW

Mango weevil infestation can be very serious because the weevil causes significant damage to the mango pulp and seed contaminating the edible portion with no external symptom of damage (Cunningham, 1989 and Srivastata, 1997). Infestation of MSW has been reported to reach 43% - 80% in the Philippine, Hawaii and India (De Jesus and Cortez, 1998; Follett, 2009; Verghese *et al.*, 2005a).

A mango pulp weevil (MPW) attacks young mango fruits starting from 4 to 5 weeks after fruit development (Ithnain *et al.*, 2008). The female weevil lays eggs singly on the skin of mango fruits and about 7 days after, the eggs hatch to become larvae. The newly hatch larvae bore a tunnel into mango flesh and leave the frass inside the fruits. Mango pulp larvae consume mango pulp as their only source of food.

Follett and Gabbard (2000) reported that a female mango weevil lays eggs on the epicarp of developing fruit and the larvae bore through the pulp, feed on the seed coat thus damage the cotyledons. As the fruit matures and increases in size, the mango endocarp become thickens and becomes difficult for first instars to penetrate. The eaten path turn black threads running through the fruit flesh from just under the skin to the seed surface or may not be visible at all and later they disappear completely.

The effect of MPW can be seen when the fruits are ripening. No outward signs of attack can be found on the fruits until adult weevils bore out of the fruit. Stages such as larva, pupa and adult can be found simultaneously in the mango fruits when the fruits are cut open (Plate 2.2). When the mango fruit is fully ripe, adult weevil bores an exit hole on the skin to escape from the fruits and begins searching for a place to hide such as at mango tree stump or stacking branches (De Jesus *et al*., 2003 and Ithnain *et al*., 2008), mango tree crevices (De Villiers, 1984 and De Villiers, 1989), under loose bark, in crotches in trees, under loose material beneath the trees and are able to hibernate inside the seed of the mangoes (Schoeman, 1987b).

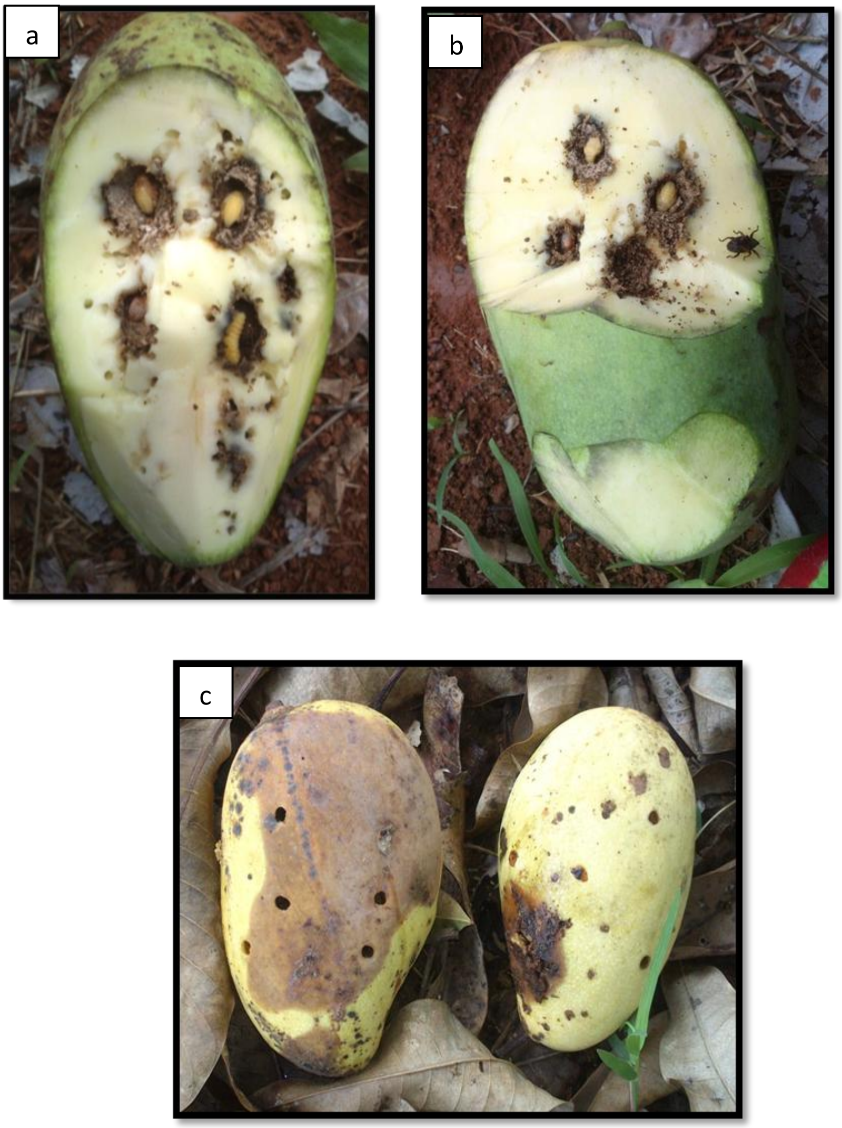

Plate 2.2: Pulp damage caused by MPW (a and b), exit holes (c).

2.8 Control methods of mango weevil

There are many methods to control mango weevil in the field, these included cultural, biological and chemical controls. An integrated pest management program incorporating cultural methods of open-center pruning and sanitation, pest monitoring and chemical control (Medina *et al.,* 2005) did not completely control the pest. Mango weevil can survive in picked fruits and is likely to be present in fruits packed for export (Ballock and Kozuma, 1964; De and Pande, 1988 and Cunningham, 1989). Exporting countries such as Hawaii and the Phillippines practice quarantine measures through irradiation before shipping the fruits to their destinations (Follett, 2009 and Lorenzana and Obra, 2013).

2.8.1 Cultural control

Cultural technique such as bagging the fruits has been practiced against the MPW. Ithnain *et al.,* (2008) suggested that mango fruits should be bagged or covered at a ping-pong ball size. Spraying of fruits with insecticide before bagging is recommended by MARDI Malaysia. (Ithnain *et al.,* 2008). Catinding and Heong (2011) have different opinion about the timing of insecticide spray. They suggest that insecticide should be applied after the chicken egg size fruits (about 55 - 60 old days) are bagged with durable papers likes imported newsprints or newspapers.

Another recommended cultural method is pruning through removing of excess and unproductive branches, opens up the tree canopy for air circulation, light penetration and ventilation. It will reduce the impact of weevil infestation on mango fruits. Well aired tree canopy will be less suitable for aestivating weevils and other pest of mango (Brahimah and Van Emden, 2010 and Catinding and Heong, 2011).

Field sanitation such as collecting infested fruits and burying them half meter deep a hole prevent the weevil from completing its life cycle. Dead branches and tree stump should be burnt to destroy the weevil"s hiding places (Catinding and Heong, 2011 and Ithnain *et al*., 2008). Planting resistant mango cultivars which have good agronomic characteristics including seedless fruit, early development of seeds, and unseasonal fruiting has been useful to control MSW (Pena *et al.*, 1998).

2.8.2 Biological control

Based on a study by Hansen (1993), predators such as ants, rodents, lizards and birds have been reported to prey on weevil adults. However Brahimah and Van Emden (2010) observed only small impact on populations of the weevil by these predators. Hansen (1993) and Peng and Christian (2007) reported that green weaver ants, *Oecophylla smaragdina* (Fabricius) are efficient biocontrol agents of the mango seed weevil but they usually bite farm operators during field maintenance, especially at harvest, pruning and fertilizer applications (Brahimah and Van Emden, 2010). In contrast, Pena *et al.*, (1998) stated that no effective natural enemies specific to the weevil has been recorded probably because of the life cycle of mango weevil occurs in the mango fruits.

2.8.3 Chemical control

Insecticide is widely practiced around the world for attracting mango pest. In MPW infested areas, preventive spraying is recommended when the size of mango fruits is at chicken egg size. Sprayings at 7 to 14 days interval with fenitrothion (Sumithion 50 EC, 15ml/10 l water), deltamethrin (Decis 40, 5ml/4.5l water), dimethoate (Dimet 40, 5ml/4.5 l water), cypermethrin (Chiptrin 5.5, 10ml/10 l water), and cyfluthrin (Baythroid 5 EC, 7.5ml/10 l water) are effective (Ithnain et al., 2008).

Verghese et al., (2005b) carried out a field research for three years in Alphonso mango to evaluate the efficacy of selected synthetic, botanical and animal-origin insecticides to treat MSW infestation in India. Four synthetic insecticides, deltamethrin, acephate, carbaryl and ethofenprox reduced infestation level to 3.3% and 14.8% respectively at harvest. Two biological insecticides, azadirachtin (neem oil) and fish oil rosin soap (of animal origin) are less effective. Each of the treatments only reduces the level of infestation to 27.4 and 23.0%, which are not too different from the control (33%).

Based on previous study by Pena et al., (1998), pyrethroid deltamethrin, and carbamate carbaryl are effective and each of this chemical reduces the infestation rate below 15%. Other than these insecticides, organophosphate fenthion also effective for controlling mango seed weevil (MSW) which reduces the infestation rate to less than 17%. He also recommends spot application of diazinon on tree trunks of mango to treat S. *mangiferae.*

Insecticides such as carbaryl, monocrotophos, dimethoate, deltamethrin and fenthion are widely used with high effectiveness against the pest (Bangle and Prasad, 1985; Shukla and Tendon, 1985 and Verghese et al., 1998). Similarly in Australia, deltamethrin and fenthion are used for treatment as well as methidathion, fenvalerate, esfenfalerate and triflumuron (Nel et al., 2002; Wittenberg and Pinese, 2006), Parathion (De Villiers, 1987; Schoeman, 1987a and Schoeman, 1988) and prothiofos (Grove and De Beer, 2007). Joubert et al., (2002 and 2004) found that fibronil was effective against the weevil but it tended to cause an increase in mango scale and mealybug infestation.